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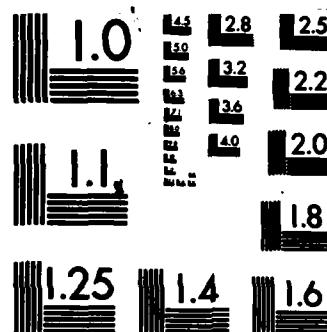
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## Fast Collisionless Tearing in an Anisotropic Neutral Sheet

J. CHEN, P. J. PALMADESSO, J. A. FEDDER, AND J. G. LYON

*Geophysical and Plasma Dynamics Branch  
Plasma Physics Division*

*\*Science Applications, Inc.  
McLean, VA 22102*

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The collisionless tearing mode in a neutral sheet is studied in the presence of ion temperature anisotropy using Vlasov description for both ions and electrons. It is found that the growth rate of the instability is significantly enhanced if $T_{\perp\perp}/T_{\parallel\parallel} > 1$ , where the symbols $\perp$ and $\parallel$ refer to the directions perpendicular and parallel to the equilibrium magnetic field. For typical magnetotail parameters with modest temperature anisotropy, it is shown that the linear e-folding time is reduced to a small fraction of the time delays believed to precede the onset of reconnection.		

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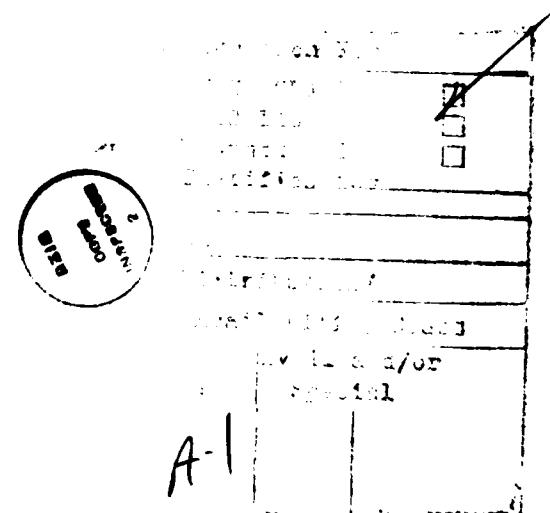
20. ABSTRACT (Continued)

This enhancement of the growth rate is due to the Lorentz force acting on the ions that cross the neutral plane and that traverse beyond the conventional electron tearing layer.

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## FAST COLLISIONLESS TEARING IN AN ANISOTROPIC NEUTRAL SHEET

### 1. INTRODUCTION

The isotropic collisionless tearing mode (Furth, 1962; Pfirsch, 1962) has been under extensive investigation for the past few decades (Laval et al., 1965; Schindler, 1966; Schindler and Soop, 1968; Dobrowolny, 1968; Biskamp and Schindler, 1971; Quest and Coroniti, 1981). In particular, it was suggested (Coppi et al., 1966) as a possible mechanism for magnetic field line reconnection in the magnetosphere (Dungey, 1961). The tearing mode may also be relevant to the dayside magnetopause (e.g., Greenly and Sonnerup, 1981; Quest and Coroniti, 1981).

The central importance of the tearing mode is that the growth rate of the instability is believed to provide a measure of the time delay for the onset of reconnection after the interplanetary magnetic field turns southward. One difficulty in identifying the conventional isotropic collisionless tearing mode as a possible mechanism for reconnection is that the instability is a weak one. For example, using the results of Dobrowolny (1968), the electron tearing growth time is estimated to be of the order of 1 hour for the tail region, which is too long to have any role. However, in a collisionless plasma, the motion of particles parallel to the magnetic field is decoupled from the perpendicular motion and temperature (and pressure) anisotropy is likely to exist (Crooker and Siscoe, 1977; Cowley, 1978).

Laval and Pellat (1968) used an energy principle analysis to show that collisionless tearing mode properties can be strongly modified by weak anisotropy. In this work, however, the eigenmode structure was not studied and quantitative estimates of the growth rate were not given. Recently, Chen and Davidson (1981) carried out a Vlasov-fluid analysis for a field-reversed ion layer at marginal stability using approximate orbits. It is

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found that slight anisotropy ( $T_{i\perp}/T_{i\parallel} > 1$ ) can increase the range of unstable wavenumbers of the tearing mode in an ion layer, indicating that the magnetopause and magnetotail properties may be affected significantly by anisotropy. Here the symbols  $\perp$  and  $\parallel$  refer respectively to the directions perpendicular and parallel to the equilibrium magnetic field. More recently, Basu and Coppi (1982) studied a fluid-like "field swelling" instability in an anisotropic plasma. This analysis is local and is based essentially on the fluid equations so that it is difficult to assess its applicability to the tearing mode which is due to the large orbits crossing the neutral line.

Because the previous works have not been able to provide the dispersion relation, the importance of the anisotropy effects has not been appreciated. In this paper, we calculate the anisotropic dispersion relation and show that the tearing mode growth rate for a collisionless neutral sheet can be strongly enhanced if the temperature distribution is anisotropic ( $T_{\perp} > T_{\parallel}$ ). In light of the new results, we reconsider some aspects of the reconnection processes in the open magnetosphere. However, the detailed mathematical treatment of the plasma physics aspects is not appropriate here and will be published elsewhere (Chen and Palmadesso, 1983). As a general remark, we note that the real magnetotail has a small normal component of the magnetic field which may be stabilizing to collisionless tearing mode because the electrons can be magnetized (Galeev and Zelenyi, 1976; Lembege and Pellat, 1982). However, ions may still be unmagnetized, giving rise to an "ion tearing mode" (Schindler, 1974). In addition, pitch angle scattering may tend to destabilize the mode (Coroniti, 1980) as well as isotropize electron anisotropy. In the present work, we do not include the normal field or pitch angle scattering.

Because the above effects tend to affect primarily the electrons, we will take the electrons to be isotropic and include only anisotropic ions.

## 2. ANISOTROPIC TEARING-MODE INSTABILITY

The perturbation considered has the form  $\psi(x, z, t) = \hat{\psi}(z)\exp(ikx - i\omega t)$ . The wavevector  $\underline{k} = k_x$  is parallel to the equilibrium magnetic field  $\underline{B}_0(z) = B_0(z)\underline{x}$ , which is generated self-consistently by the current density  $\underline{J}_0 = J_0\underline{y}$ . For the tearing mode, we have  $\omega \ll \omega_{ci}$  where  $\omega_{ci}$  is the ion cyclotron frequency in the asymptotic field  $B_0 = B_0(z \rightarrow \infty)$ . In addition, for the parameters of interest, we also have  $\omega \ll kv_{th}$  where  $v_{th}$  is the thermal velocity of the particles. In this paper, we adopt for both ions and electrons ( $j = i, e$ ) Harris-type equilibrium distribution functions given by  $f_{0j}(H_{\perp j} - v_j p_{yj}, H_{\parallel j})$

$$= \frac{n_0}{2\pi T_{\perp j}/m_j} \frac{1}{\sqrt{2\pi T_{\parallel j}/m_j}} \exp\left[-\frac{1}{T_{\perp j}} (H_{\perp j} - v_j p_{yj})\right] \exp\left(-\frac{1}{T_{\parallel j}} H_{\parallel j}\right), \quad (1)$$

where  $H_{\perp j} = (m_j/2)(v_y^2 + v_z^2)$ ,  $p_{yj} = m_j v_j + (q_j/c)A_y^0(z)$ ,  $H_{\parallel j} = (m_j/2)v_x^2$ ,  $v_j = \text{constant}$  is the mean velocity of the species  $j$ , and  $A_y^0(z)$ , is the vector potential for the equilibrium magnetic field. The electrostatic field is taken to be zero in the frame of the neutral sheet and charge neutrality will be assumed. Then the self-consistent equilibrium quantities are well-known and are given by  $n_0(z) = n_0 \operatorname{sech}^2(z/\delta)$  and  $B_x^0(z) = B_0 \tanh(z/\delta)$ , where  $B_0 \equiv (8\pi n_0 T_{\perp})^{1/2}$ ,  $T_{\perp} \equiv T_{i\perp} + T_{e\perp}$  and

$$\delta \equiv \left(\frac{c^2 T_{\perp}}{2\pi n_0}\right)^{1/2} \frac{1}{e(v_i - v_e)}. \quad (2)$$

Using the method of characteristics, the linearized Vlasov distribution function for each species can be written as

$$f_{1j} = \frac{q_j \beta_j}{T_{j\perp}} f_{0j} \psi - \frac{i\omega q_j}{T_{j\perp}} f_{0j} Q_y + \frac{ik q_j}{T_{j\perp}} \left(1 - \frac{T_{j\perp}}{T_{j\parallel}}\right) f_{0j} v_x^0 v_y^0 \quad (3)$$

where

$$Q_y \equiv -\frac{1}{c} \int_{-\infty}^t dt' v_y' \psi. \quad (4)$$

Here,  $\beta_j \equiv v_j/c$ ,  $c$  is the speed of light, and  $\psi(x, z, t) \equiv A_{1y}(x, z, t)$  is the perturbed vector potential. In equation (3), use has been made of  $\partial/\partial t \rightarrow -i\omega$  and  $\partial/\partial x \rightarrow ik$ . In obtaining equations (3) and (4), we have used  $\phi \ll (\omega/kv_{th})(v_y/c)\psi$  which is a consequence of charge neutrality at low perturbation frequencies (Dobrowolny, 1968). Here,  $\phi$  is the perturbed scalar potential. Using equation (3) in Ampere's law, we obtain

$$\frac{d^2 \hat{\psi}}{dz^2} - k^2 \hat{\psi} = -\frac{4\pi}{c} \sum_j q_j \int d^3 v \frac{v_y}{v_x} f_{1j} \quad (5)$$

where  $\hat{\psi}(z) \equiv \psi(x, z, t) \exp(-ikx + \omega t)$ .

In the isotropic limit,  $T_{j\perp}/T_{j\parallel} = 1$ , the last term of equation (3) vanishes and the isotropic results are recovered. For the anisotropic case, estimating  $v_x$  by the typical thermal velocity  $v_{th}$ , we see that the second term is smaller than the last term by approximately  $\omega/(kv_{th}) \ll 1$  so that the anisotropy term is dominant unless the degree of anisotropy is small. In order to evaluate  $Q_y$  and  $f_{1j}$  quantitatively, we note that the component  $v_y$  is nearly constant for a typical particle in the inner regions ( $|z| < d_j$ ,  $j = i, e$ ) where the magnetic field is weak and that a typical

particle is magnetized in the outer regions ( $|z| > d_j$ ). Here, we take  $d_i \equiv \sqrt{a_i \delta/2}$  and  $d_e \equiv \sqrt{2a_e \delta}$ , where  $a_j$  is the Larmor radius of a thermal particle of species  $j$ . These approximations are intended to model the various particle orbits as described by, for example, Sonnerup (1971). In addition,  $\hat{\psi}(z)$  is assumed to be nearly constant (constant- $\psi$  approximation) in the inner regions. In the outer regions  $|z| > d_j$ , the particles execute the usual  $\nabla B$  drift motion.

Using the above approximations, after some algebra, we obtain for each species in the respective inner regions ( $|z| < d_j$ )

$$Q_y^{in} = i c^{-1} v_y \hat{\psi}(z) (kv_x - \omega)^{-1} \exp(ikx - i\omega t) \quad (6)$$

and in the respective outer regions ( $|z| > d_j$ )

$$Q_y^{out} = i c^{-1} v_D^j \hat{\psi}(z) (kv_x - \omega)^{-1} \exp(ikx - i\omega t) \quad (7)$$

The quantity  $v_D^j$  is the usual  $\nabla B$  drift velocity in the  $y$ -direction. Using equations (3), (5), (6) and (7), it is clear that equation (5) is an eigenvalue equation for  $\hat{\psi}(z)$ , subject to the conditions that its first derivative  $(\partial \hat{\psi} / \partial z)$  vanish asymptotically ( $|z| \rightarrow \infty$ ) and that the logarithmic derivative be continuous at  $|z| = d_e$  and  $|z| = d_i$ . However, unlike the conventional isotropic tearing-mode calculations in neutral sheets (see for example, Dobrowolny, 1968) in which the "inner" solution for  $|z| < d_e$  is matched to the "outer" solution for  $|z| > d_i$ , it is found that the dispersion relation for the anisotropic tearing-mode is critically affected by the ion orbits in the "intermediate" region  $d_e \leq |z| \leq d_i$ . Therefore, the eigenvalue equation (5) must be solved in the above three regions. For

the inner region, an analytical solution can be obtained. In the intermediate and outer regions, the equation is solved numerically. The resulting dispersion relation, obtained by matching the logarithmic derivative of  $\psi$  at  $z = d_e$  and  $z = d_i$  (three-region approximation), is shown in Figure 1 for several values of  $T_{i\parallel}/T_{i\perp}$  with  $\alpha_i/\delta = 0.1$ .

The first point to note is that  $\gamma/\omega_{ci}$  and hence the associated values of  $\gamma/kv_i$  and  $\gamma/kv_e$  are all substantially less than unity, justifying the low frequency approximations a posteriori. Another point to note is that curve b for the isotropic case is nearly equal to the conventional two-region result with the present three-region growth rates being slightly smaller. This reduction in  $\gamma$  can be traced to the  $\nabla B$  contributions. As  $\alpha_i \equiv T_{i\parallel}/T_{i\perp}$  is increased, the growth rate and the range of unstable  $k$  numbers both increase substantially. For example, the maximum growth rate for  $\alpha_i = 1.5$  is  $\gamma = 2.2 \times 10^{-3} \omega_{ci}$  compared with the isotropic maximum growth rate  $\gamma = 1.9 \times 10^{-4} \omega_{ci}$  for the same parameters, an enhancement by a factor of 10. The wavelength at maximum  $\gamma$  is reduced to roughly 2.75 from 27. For  $\alpha_i < 1$ , even a small deviation from isotropy strongly stabilizes the mode as shown by curve a of Figure 1. This latter behavior is consistent with the conclusion of Laval and Pellat (1968). Physically, the anisotropy effects discussed are due to the Lorenz force which is similar to the mirror forces (the third term of equation (3)). Note also that Hill (1975) found that the magnetic merging is enhanced when  $p_{\perp} > p_{\parallel}$ .

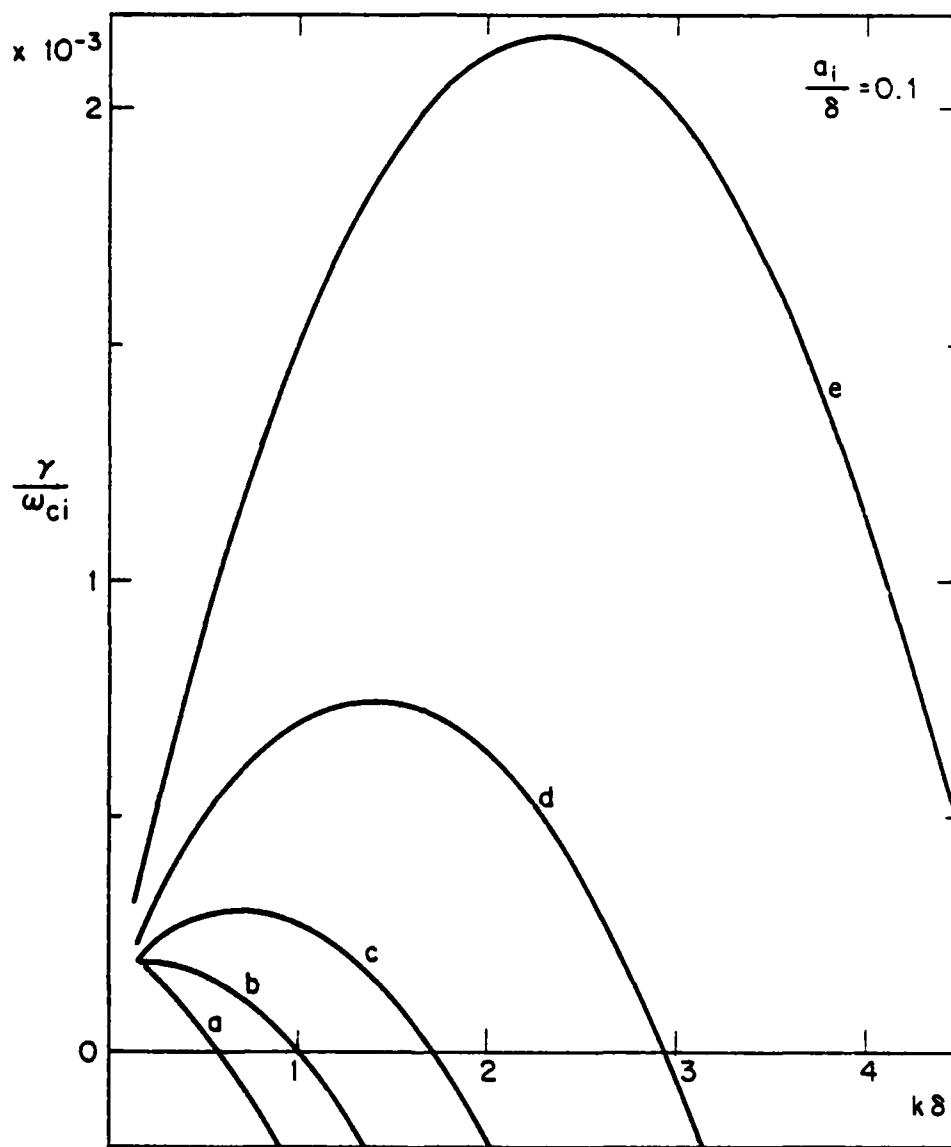


Fig. 1. Normalized growth rate ( $\gamma/\omega_{ci}$ ) versus  $k\delta$  with  $a_i/\delta = 0.1$  and isotropic electrons. The value of  $T_{i\perp}/T_{i\parallel}$  is (a) 0.9, (b) 1.0, (c) 1.1, (d) 1.25 and (e) 1.5. The curves are not completed near  $k\delta = 0$  because a number of approximations break down for  $k \rightarrow 0$ .

### 3. DISCUSSION

Two regions where the preceding results may be relevant are the neutral regions of the magnetotail and the dayside magnetopause. In this regard, we note that the need to include temperature anisotropy in these regions has been pointed out (Crooker and Siscoe, 1977; Cowley, 1978). We will use some parameters suitable for the neutral region in the tail for illustration. For example, for 1keV ions,  $\alpha_i/\delta = 0.1$ ,  $T_{ii}/T_{e\perp} = 2$  and  $B_0 = 20\gamma$ , we obtain  $\omega_{ci} \approx 1.9\text{sec}^{-1}$  and Figure 1 (curve b) yields the minimum e-folding time  $(\gamma_{\max}^{-1}) \approx 45$  minutes for the isotropic case. If  $\alpha_i = 1.25$ , then  $(\gamma_{\max}^{-1}) \approx 12$  minutes. For  $\alpha_i = 1.5$ , we have  $(\gamma_{\max}^{-1}) \approx 4$  minutes, a reduction by more than one order of magnitude. This shows that, in the presence of even small to modest ion temperature anisotropy, the e-folding time scale is a small fraction of the delay time of roughly 30 minutes for the onset of reconnection. We, therefore, conclude that the anisotropic collisionless tearing mode may indeed play an important role in reconnection processes in the magnetosphere. It is important to note that no classical or anomalous resistivity is used in our calculation. Further increase in  $\alpha_i$  yields even greater enhancement in the growth rate. However, the approximations used in the analysis begin to break down for much larger  $\alpha_i$  so that we are not able to make quantitative statements for large degrees of anisotropy.

So far, the anisotropic tearing mode results have been considered in the context of the tail region. In the neutral region of the dayside magnetopause,  $\alpha_i/\delta$  may be nearly unity, which is outside the regime of validity of the present analysis. However, we expect qualitatively similar effects to occur. Note also that only the linear regime has been investigated and we cannot draw definitive conclusions concerning the

possible magnetic island formation. However, we speculate that the saturation level in the presence of anisotropy is greater than in the absence of anisotropy. Subsequent to the work of Chen and Palmadesso (1982), numerical simulations have been performed using a one-component plasma (hot ions and cold electrons) (Ambrosiano and Lee, 1983) and the preliminary results indicate that the growth rate and the saturation amplitudes both increase substantially as  $\alpha_i$  is increased from unity.

As discussed in Section 1, the magnetotail possesses a number of features such as the weak normal component of the magnetic field and pitch angle scattering that are not included in the present analysis. So far, these modifications have been applied to the isotropic tearing mode in the literature. In view of the fact that anisotropic tearing mode completely dominates the isotropic case, we suggest that tearing instability in the presence of anisotropy is the more relevant perturbation to investigate and that the above modifications should be considered for the anisotropic case. Moreover, since the enhancement of the growth rate is primarily due to the large ion orbits, we expect qualitatively similar effects to persist even if the above refinements are included.

#### ACKNOWLEDGMENT

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## REFERENCES

Ambrosiano, J.J. and L.C. Lee, Simulation of ion tearing mode instability in the presence of temperature anisotropy, EOS, 64, 293, 1983.

Basu, B. and B. Coppi, Field-swelling instability in anisotropic plasmas, Phys. Rev. Lett., 48, 799, 1982.

Biskamp, D. and K. Schindler, Instability of two-dimensional collisionless plasmas with neutral points, Plasma Phys., 13, 1013, 1971.

Chen, J. and R.C. Davidson, Tearing-mode stability properties of a diffuse anisotropic field-reversed ion layer at marginal stability, Phys. Fluids, 24, 2208, 1981.

Chen, J. and P.J. Palmadesso, EOS, 63, 1063, 1982.

Chen, J. and P. Palmadesso, Tearing instability in an anisotropic neutral sheet, NRL Memo. Report 5178, 1983 AD/A132 684. Submitted to Phys. Fluids.

Coppi, B., G. Laval, and R. Pellat, Dynamics of the geomagnetic tail, Phys. Rev. Lett., 16, 1207, 1966.

Coroniti, F.V., On the tearing modes in quasi-neutral sheets, J. Geophys. Res., 85, 6719, 1980.

Cowley, S.W.H., The effect of pressure anisotropy on the equilibrium structure of magnetic current sheets, Planet. Space Sci., 26 1037, 1978.

Crooker, N.U. and G.L. Siscoe, A mechanism for pressure anisotropy and mirror instability in the dayside magnetosheath, J. Geophys. Res., 82, 185, 1977.

Dobrowolny, M., Instability of a neutral sheet, Nuovo Cimento B, 55, 427, 1968.

Dungey, J.W., Interplanetary magnetic field and the auroral zones, Phys. Rev. Lett., 6, 47, 1961.

Furth, H.P., The "mirror instability" for finite particle gyroradius, Nucl. Fusion Suppl. Pt. 1, 169, 1962.

Galeev, A.A. and L.M. Zelenyi, Tearing instability in plasma configurations, Sov. Phys. JETP, 43, 1113, 1976.

Greenly, J.B. and B.U.O. Sonnerup, Tearing modes at the magnetopause, J. Geophys. Res., 86, 1305, 1981.

Hill, T.W., Magnetic merging in a collisionless plasma, J. Geophys. Res., 80, 4689, 1975.

Hoh, F.C., Stability of sheet pinch, Phys. Fluids, 9, 277, 1966.

Laval, G., R. Pellat and M. Viellemin, Instabilités électromagnétiques des plasmas sans collisions, in Plasma Physics and Controlled Nuclear Fusion Research (International Atomic Energy Agency, Vienna, 1966), Vol. II, 259.

Laval, G. and R. Pellat, Stability of the plane neutral sheet for oblique propagation and anisotropic temperature, ESRO SP-36, 5, 1968.

Pfirsch, D., Z. Naturforsch, 17a, 861, 1962.

Quest, K.B. and F.V. Coroniti, Linear Theory of Tearing in a High- $\beta$  Plasma, J. Geophys. Res., 86, 3299, 1981.

Quest, K.B. and F.V. Coroniti, Tearing at the dayside magnetopause, J. Geophys. Res., 86, 3289, 1981.

Schindler, K., A theory of the substorm mechanism, J. Geophys. Res., 79, 2803, 1974.

Schindler, K., 1966, in Proceedings of the Seventh International Conference on Phenomena in Ionized Gases (Gradevinska Knjiga, Beograd, Yugoslavia, 1966), Vol. II, 736.

Schindler, K. and M. Soop, Stability of plasma sheaths, Phys. Fluids, 11, 1192, 1968.

Sonnerup, B. U. Ö., Adiabatic particle orbits in a magnetic null sheet J.  
Geophys. Res., 76, 8211, 1971.

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J. DeGroot  
L. Wood  
J. Emmett  
B. Lasinsky  
B. Langdon  
R. Briggs  
D. Pearlstein

Los Alamos National Laboratory  
P.O. Box 1663  
Los Alamos, New Mexico 87545  
ATTN: Library  
D. Forslund  
J. Kindel  
B. Bezzerides  
H. Dreicer  
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R. Boyer  
C. Nielson  
E. Lindman  
L. Thode

Y.O.A.A.  
325 Broadway S.  
Boulder, Colorado 80302  
ATTN: J. Weinstock  
Thomas Moore (SEL, R-43)  
W. Bernstein  
D. Williams

Sandia Laboratories  
Albuquerque, New Mexico 87115  
ATTN: A. Toepfer  
G. Yeonas  
D. VanDevender  
J. Freeman  
T. Wright

Bell Laboratories  
Murray Hill, New Jersey 07974  
ATTN: A. Hasegawa

Lockheed Research Laboratory  
Palo Alto, California 94304  
ATTN: M. Walt  
J. Cladis

Physics International Co.  
2400 Merced Street  
San Leandro, California 94577  
ATTN: J. Benford  
S. Putnam  
S. Stalings  
T. Young

Science Applications, Inc.  
Lab. of Applied Plasma Studies  
P.O. Box 2351  
LaJolla, California 92037  
ATTN: L. Linson  
J. McBride

Goddard Space Flight Center  
Greenbelt, Maryland 20771  
ATTN: M. Goldstein  
T. Northrop  
T. Birmingham

TRW Space and Technology Group  
Space Science Dept.  
Building R-1, Room 1170  
One Space Park  
Redondo Beach, California 90278  
ATTN: R. Fredericks  
W.L. Taylor

National Science Foundation  
Atmospheric Research Section (ST)  
Washington, D.C. 20550  
ATTN: D. Peacock

Goddard Space Flight Center  
Code 961  
Greenbelt, Maryland 20771  
ATTN: Robert F. Benson

NASA Headquarters  
Code EE-8  
Washington, D.C. 20546  
ATTN: Dr. I. Schmerling  
Dr. J. Lynch  
Dr. D. Butler

Klumpar, David  
Center for Space Sciences  
P.O. Box 688  
University of Texas  
Richardson, Texas 75080

Leung, Philip  
Dept. of Physics  
University of California  
405 Hilgard Avenue  
Los Angeles, California 90024

Lysak, Robert  
School of Physics and Astronomy  
University of Minnesota  
Minneapolis, MN 55455

Schulz, Michael  
Aerospace Corp.  
A6/2451, P.O. Box 92957  
Los Angeles, California 90009

Shawhan, Stanley  
Dept. of Physics & Astronomy  
University of Iowa  
Iowa City, Iowa 52242

Temerin, Michael  
Space Science Lab.  
University of California  
Berkeley, California 94720

Vlahos, Loukas  
Dept. of Physics  
University of Maryland  
College Park, Maryland 20742

Matthews, David  
IPST  
University of Maryland  
College Park, Maryland 20742

Schunk, Robert W.  
Utah State University  
Dept. of Physics  
Logan, Utah 84322

Director,  
Department of Energy  
ER20:GTN, High Energy &  
Nuclear Physics  
Attn: Dr. Terry Godlove  
Washington, D.C. 20545

Director,  
Department of Energy  
Office of Inertial Fusion  
Attn: Dr. Richard Schriever  
Washington, D.C. 20545

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